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Benchmarking the effect of weather data upon energy estimation of UK homes

Gavin Murphy, John Allison, John Counsell
Department of Mechanical and Aerospace Engineering,
University of Strathclyde, Glasgow.
gavin.murphy@strath.ac.uk

Abstract
This paper extends a fundamental dynamic method of assessing the controllability of a building and its servicing systems: IDEAS – Inverse Dynamics based Energy Assessment and Simulation. IDEAS produces results which are calibrated with the UK Government's Standard Assessment Procedure (SAP). The extension presented is a measure of the effect upon energy estimation by varying climactic data, using CIBSE TRY/DSY weather data for 14 locations across the UK. A calibrated standard test case dwelling is initially modelled in IDEAS and SAP. Using each of the CIBSE weather locations, the variation in energy estimation of the standard test case dwelling is analysed. Results suggest that use of localised weather data can have a noteworthy effect on energy estimation and can play an important role on delivering buildings which are truly fit for purpose.

Keywords Dwellings, Standard Assessment Procedure (SAP), IDEAS, CIBSE TRY/DSY weather data

1.0 Introduction

The European Directive on the Energy Performance of Buildings [1, 2], referred to as the Energy Performance of Buildings Directive (EPBD) stipulates that all European member states must produce an Energy Performance Certificate (EPC) whenever buildings are constructed, sold or rented. In the UK, SAP is the procedure used to generate an EPC. SAP is the recognised method for building professionals to meet buildings compliance and is the culmination of three decades of research commencing with BREDEM 1 [3, 4].

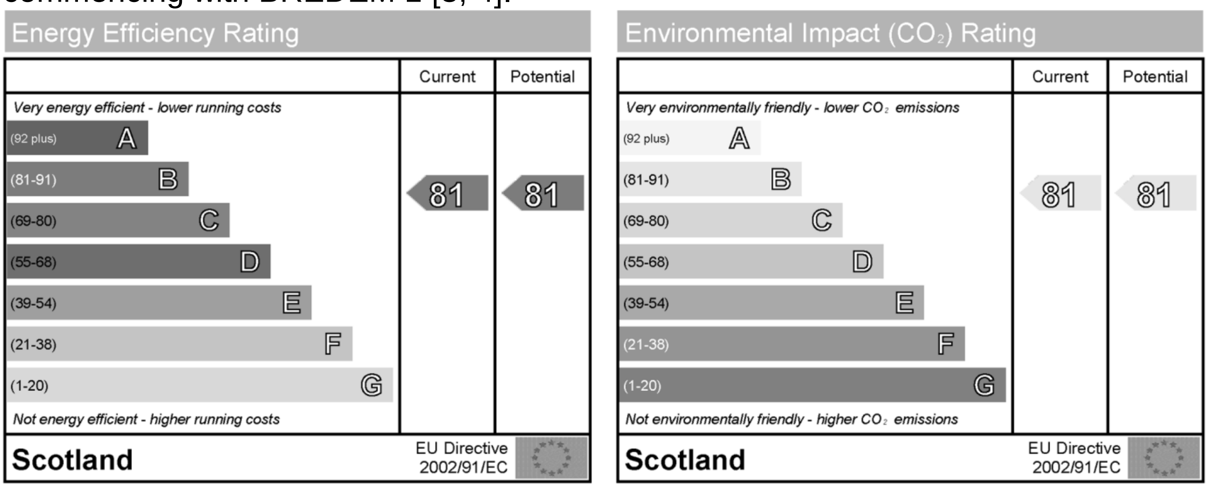

Figure 1 - Sample SAP derived Energy Efficiency and Environmental Impact Ratings for Scotland

Studies have shown that there can be variances in results between SAP and dynamic simulation tools [5]. Fundamental dynamic methods have been shown to be relevant for controllability analysis [6-8] and for the assessment of buildings [9]. A benefit of dynamic systems modelling is that a state space model [10] can rapidly and thoroughly determine the effect of disturbances such as free heats gains or external temperature [11].

A novel advanced dynamic calculation method (IDEAS) of assessing the controllability of a building and its servicing systems has been developed. IDEAS has been calibrated over a large range of test cases with SAP [12].

SAP estimates the energy estimation of a dwelling based upon a notional central location for the UK, taken as East Pennines region, this allows for dwellings to be compared on a like-for-like-basis as one weather location allows for one set of solar and one set of external temperatures to be used for each dwelling evaluated in SAP. External temperatures and solar gain can have a critical impact on the energy estimation of a home. In addition to this, factors such as occupancy and appliance heat gains are assumed based upon the total floor area of the dwelling. The assumptions made in SAP, how they compare with BREDEM, and SAP's use for EPBD compliance has been previously researched and published [13].

Given SAP's role in energy estimation and its use of specific assumptions for all dwellings, it is important to quantify the effect of using the current single climactic location in comparison with the use of several more localised climactic locations. The focus of this paper is measuring the effect upon energy estimation by varying external temperature data, using CIBSE TRY/DSY weather data for 14 locations across the UK.

2.0 METHODOLOGY

2.1 Developing a modelling environment

An IDEAS based modelling environment was selected for this study. IDEAS allows for an extension of SAP in many areas, such as: the ability to make use of various dynamic weather files [14] and the flexibility to amend the heating setpoint which is tracked (for example, comparisons can be made between tracking a constant setpoint vs. a varying setpoint). IDEAS has been described in depth [15, 16].

Any set-point can be tracked in the IDEAS method, the set-point tracked in this IDEAS model is based upon the standard SAP temperature demand profile (see Figure 2).

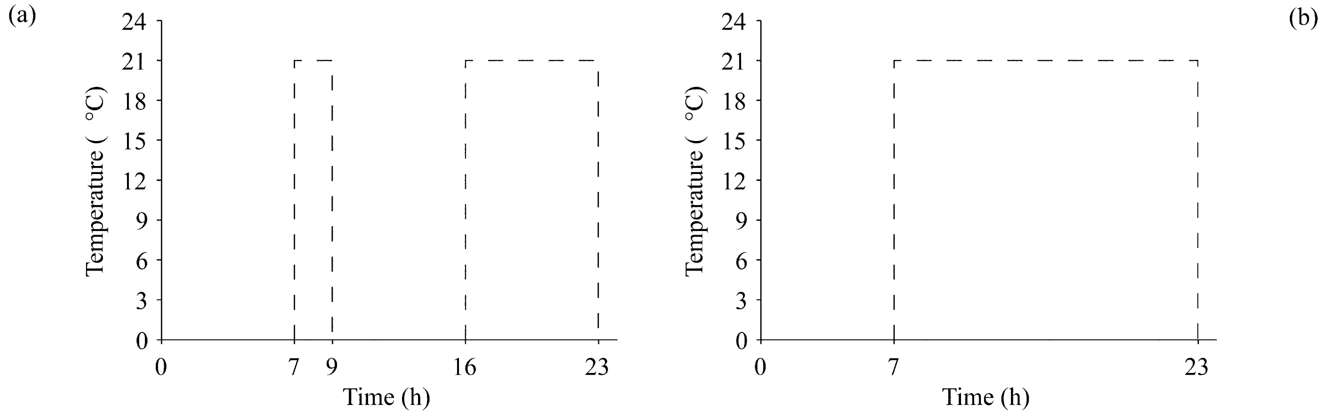

Figure 2 - Standard SAP temperature demand profile (a) weekdays; (b) weekends

By tracking the standard SAP temperature demand profile setpoint, IDEAS will calculate what the predicted energy consumption for that modelled dwelling over a year. This energy use will be affected by factors such as weather data and heat gains from appliances.

In IDEAS, heat gains such as external weather data and heat gains from appliances are described as disturbances to the model. These disturbances are taken into account by IDEAS and play an important part in the overall energy estimation analysis of a dwelling. For example, if there are more heat gains then less heating could be required to be produced by the heating system for the standard SAP temperature demand profile to be met. The focus of this paper is the effect of the external temperature component from CIBSE TRY/DSY weather data for 14 locations across the UK and measuring the impact of this weather variation on the predicted energy performance of dwellings.

2.2 Disturbance heat gains

In this IDEAS model dynamic time-varying solar gains and external temperature are used. A disturbance heat gain into the building is used that is a combination of solar radiation, metabolic heat gains, and heat gains from electrical devices.

Disturbance free heats gains must also be calibrated, which is comprised of weather profiles, lighting, appliance and metabolic gains. SAP makes assumptions for factors such as occupancy and hot water use based upon the ‘total floor area’ of a dwelling; a single representative weather location (taken as East Pennines, UK) is used as the basis for solar gains. Appliance gains were taken from an International Energy Agency / Energy Conservation in Buildings and Community Systems Program (ECBCS) Annex 42 study based upon real UK test data for 69 monitored buildings [17]. Appliance gains were fixed for each of the test cases in this study.

Solar radiation data for the East Pennines, UK was imported into the IDEAS model for calibration with SAP, using a data file from Meteonorm [18]; this was used to provide data for the solar radiation. Solar data was fixed for each of the test cases in this study.

CIBSE TRY/DSY weather data for 14 locations across the UK was used to provide yearly external temperature for each of the test cases. The modification of the external temperature and subsequent analysis on the energy performance of dwellings is the focus of this study.

2.3 Baseline Calibration results

This IDEAS model has been calibrated against SAP over a range of test cases; in this paper one test case is presented as a baseline: Standard Test Case (unfilled cavity construction).

A standard construction dwelling was modelled, with a structure U-Value of $1 W/m^2K$, which is representative of unfilled cavity wall structure. Full test case parameters are provided in Appendix A, Table A1.

The following results were obtained when taking the mean monthly temperature and energy values from SAP and comparing these with the calculated mean monthly temperature and energy values calculated by this IDEAS model.

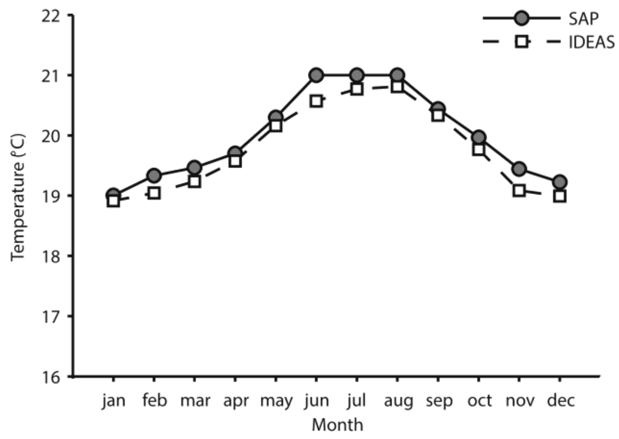

Figure 3 - Test Case 1: mean monthly zone temperature comparison

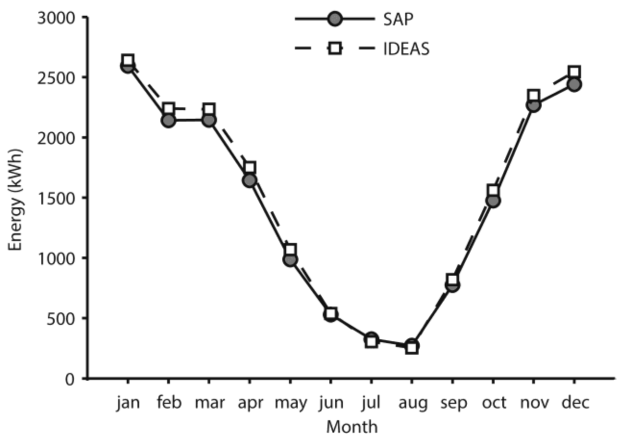

Figure 4 - Test Case 1: mean monthly energy comparison

Figure 3 and Figure 4 demonstrate the similarity between IDEAS and SAP outputs when monthly values are plotted against each other. From the data used to plot Figure 3, monthly zone temperatures, a data match of 98.9% was achieved when the arithmetic means (AM) calculated from SAP (AM = 19.77°C) and IDEAS (AM = 19.99°C) outputs were compared. Similarly for Figure 4, monthly energy consumption a match of 96.16% was found between an IDEAS AM of 17,601kWh/year and a SAP AM of 18,304kWh/year. Based upon results from the standard test case, modelling a dwelling of unfilled cavity construction, there is close match between this IDEAS model and SAP for both temperature and energy consumption.

The standard test case and calibration highlighted in Figures 3 and 4 are based upon an external temperature profile for Manchester, as taken from the CIBSE weather data.

The standard test case is used a baseline for the remainder of this paper analysing the effect of varying external temperature on energy estimation.

3.0 CIBSE TRY/DSY weather analysis
3.1 Introduction

CIBSE Test Reference Years (TRYs) and Design Summer Years (DSYs) are available for 14 locations across the UK. The importance of weather data has been highlighted: “weather data has now become an essential component of virtually every new building design and major refurbishment”[19].

Table 1 provides the results from a statistical analysis performed on the CIBSE weather data.

Table 1 - Weather data statistical analysis

Location	Latitude (°N)	Mean Temperature (°C)	Standard Deviation	Coefficient of Variation
Glasgow	55.97	8.6685	5.4258	0.625921
Edinburgh	55.95	8.8041	5.1438	0.584251
Newcastle	54.9833	9.5952	4.9305	0.513851
Belfast	54.6	9.1794	4.9679	0.541201
Leeds	53.81	10.1719	5.5657	0.547164
Manchester	53.48	10.0023	5.2695	0.526829
Nottingham	52.97	9.6261	5.6518	0.587133
Norwich	52.65	10.1009	5.4631	0.540853
Birmingham	52.48	9.8879	5.8724	0.593898
Swindon	51.5642	9.8772	5.535	0.560381
London	51.5171	11.4412	5.8185	0.508557
Cardiff	51.478	10.4426	4.8871	0.467996
Southampton	50.9339	10.9566	5.4454	0.496997
Plymouth	50.3706	11.1022	4.3692	0.393544

The locations are ordered by their latitude from the top of the British Isles to the bottom. The latitude given is for the city, which is an approximate location of actual CIBSE weather location. The standard deviation is provided to highlight the variability of the temperature of each location from its mean temperature over the year. Results indicate a reasonably large temperature swing from their mean, in line with the wide variance expected of British weather. The coefficient of variation (CV) is an indication of how the standard deviation relates to the mean. The closer the CV is to zero, the greater the uniformity of the weather. As highlighted above, the weather is generally more varied in Scotland and the North of England as opposed to Wales and Southern England.

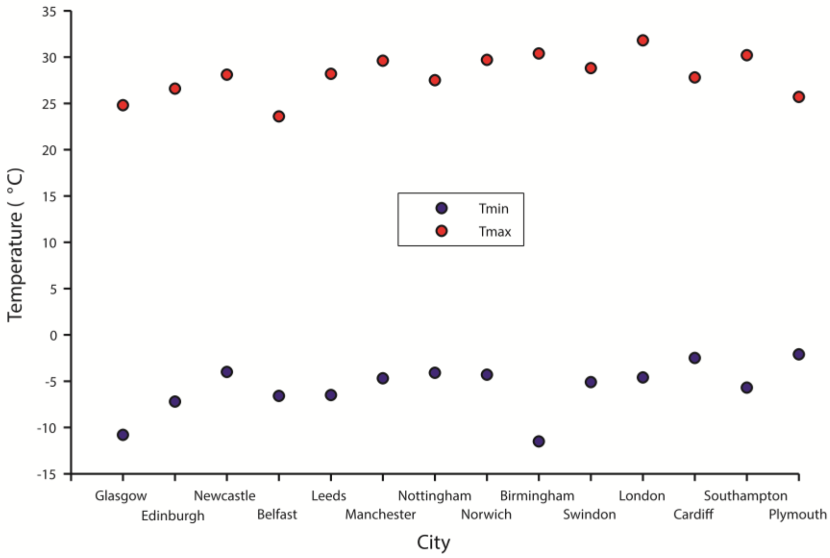

Figure 5 – Minimum and maximum external temperatures for each CIBSE TRY/DSY Weather Location

Figure 5 highlights the minimum and maximum external temperatures for each CIBSE TRY/DSY weather location. It can be viewed from Figure 5 that there is a variance of approximately 8ºC between the maximum temperatures and also the minimum temperatures when comparing the weather locations as a whole.

3.2 Distribution Spread

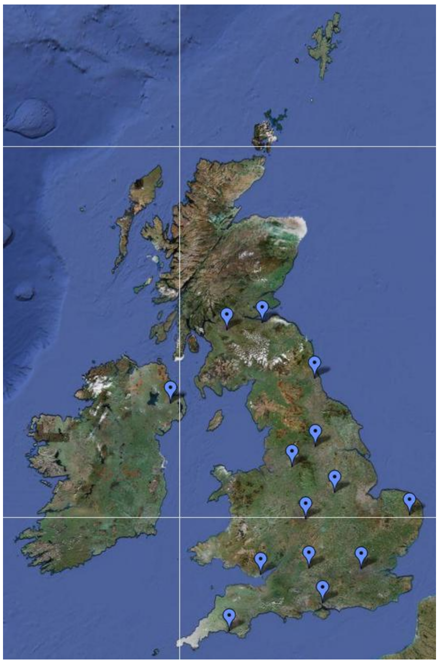

Figure 6 – CIBSE Weather location distribution spread

Figure 6 highlights the distribution spread of the CIBSE TRY/DSY weather files. The markers placed on figure 6 correspond with the locations of the available weather data. It is clear that although the main population density areas of the UK are covered, there are large areas where there is no weather data available.

4.0 RESULTS

4.1 Yearly calculated dwelling energy use for each CIBSE weather location

Table 2 presents the results of 14 IDEAS simulations based upon the Test Case 1 dwelling. Table 2 presents each of the CIBSE weather locations sorted by the yearly energy required for the standard test case dwelling (figures 3 and 4) to meet the Standard SAP temperature demand profile (figure 2).

Table 2 – Results highlighting yearly energy use for Test Case 1 for each CIBSE weather location

Number	Location	Yearly Energy (kWh)	Variation from (8), kWh	Variation from (8), %
1	Glasgow	20199	2598	14.76%
2	Edinburgh	19918	2317	13.16%
3	Belfast	19097	1496	8.50%
4	Nottingham	18551	950	5.40%
5	Newcastle	18376	775	4.40%
6	Birmingham	17913	312	1.77%
7	Swindon	17885	284	1.61%
8	Manchester	17601	0	0.00%
9	Leeds	17422	-179	1.02%
10	Norwich	17411	-190	1.08%
11	Cardiff	16519	-1082	6.15%
12	Southampton	15725	-1876	10.66%
13	Plymouth	15117	-2484	14.11%
14	London	14985	-2616	14.86%

Weather location 8, Manchester, is taken as the weather location most representative of that used in SAP; the variation of each weather location from the Manchester data analysis is presented. It was found that the weather locations where most energy is required is Glasgow and Edinburgh. The location where the least energy is required is London. It might have been expected that Southampton, Plymouth and Cardiff would require less yearly energy due to their southerly location. However, London's mean temperature is the highest out of all of the CIBSE weather locations (see Table 1) and this will have a major bearing of the predicted energy consumption.

4.2 Implications for SAP and EPC generation

The current method of SAP, SAP 2009 [20] generates EPCs for dwellings in the UK based upon a notional centre of the UK – the East Pennines location. This is taken as a representative location for the UK as a whole. Mean external temperatures are derived from this location. From Table 2, location number 8, Manchester is the most applicable CIBSE weather location for the SAP East Pennines region. The results for Manchester can be seen to be centrally distributed between the other weather locations: this is to be expected based upon the approximately central location of Manchester.

Table 2 highlights that there is a 15% difference between results when the SAP UK average Manchester location and Glasgow is compared. Therefore, when an EPC is produced at present for a dwelling in Glasgow its SAP calculated yearly energy and hence EPC rating is actually 15% better than it would be if a more localised weather location was used. Similarly, there is a 15% difference in results between the SAP calibrated standard test case with the SAP UK average Manchester location and the London weather: therefore a London dwelling modelled in SAP will be penalised by 15% due to the use of non-location specific weather data.

5.0 Conclusion

Results suggest that use of localised weather data can have a noteworthy effect on energy estimation and can play an important role on delivering buildings which are truly fit for purpose. The use of CIBSE TRY/DSY weather files has been shown to provide a wide variation of results, with energy consumption generally increasing with as the geographical latitude of the CIBSE weather location.

The spread and variation of the CIBSE weather files has been highlighted: the most accurate weather data to use is that which is closest to the location where the modelled building exists or will exist. The CIBSE weather file spread is good and most major population centres have been well covered but there are large geographical areas of the British Isles where no weather data exists.

For delivering buildings which are truly fit for purpose, internal heat gains and building location are becoming more important at the design stage and also once a building is occupied. The research here has highlighted that weather data can have a significant bearing on simulated kWh/year output: a swing of +-15% in calculated energy consumption can be seen based purely upon the external temperature variation simulated in IDEAS from the 14 CIBSE weather locations.

5.1 Discussion and Future Work

For the purposes of this study, the focus was the effect upon yearly external temperature profiles to energy estimation of a calibrated dwelling. Future work could be carried out by making use of the solar data available in the CIBSE TRY/DSY weather data, as solar gain can also be an important factor in assessing the energy performance of a building.

The effect of rain on U-values of structures could also be assessed using the IDEAS method. This is a large development task but one which can be addressed in IDEAS by the use of dynamically varying U-values, which is another aspect where IDEAS can be used to extend simplified methods such as SAP.

A new version of SAP is currently in development, SAP 2012, which will look to take into account regional variations in temperatures for costs but will still make use of a centralised climate location to determine the ratings of dwellings. Once SAP 2012 has been fully published, further work can be conducted by comparing the climactic areas selected by SAP and the climactic areas as defined by the CIBSE TRY/DSY weather location dataset. Furthermore, SAP 2012 results taking into account regional temperatures variations can be contrasted with IDEAS results using regional temperature locations to clarify the outcome of using a monthly data time-step as used in SAP against a minutely as used in IDEAS. SAP 2012 will be used to help assess properties for the Green Deal, the Energy Company Obligation (ECO) and the Renewable Heat Incentive (RHI) [21]. The draft SAP 2012 methodology has now been published and is “anticipated to come into operation in 2013” [22]. The importance of future SAP based developments highlights the need for future work to interrogate the accuracy of SAP methods and to explore any benefits of future SAP variants moving to a more dynamic platform.

The analysis of the CIBSE TRY/DSY weather locations did raise a number of queries. The distribution spread (Figure 5) highlighted that there is a lack of climactic data for large areas of the British Isles. For example, no weather data exists for areas north of Scotland's Central Belt. Future work could take weather data from another source, such as Meteonorm, for areas such as Aberdeen and analyse this accordingly. These results could suggest if additional climactic regions should be considered for conclusion in the main CIBSE TRY/DSY dataset.

The building design vs. building performance gap will increase the importance of tools used to model buildings in the future; furthermore recent research demonstrates the importance of SAP and its current place in the regulatory framework [23]. This highlights the dwelling design versus dwelling performance gap and the importance of rigour in methods such as SAP. Methods such as IDEAS can be an important part of this discussion and can suggest how methods such as SAP could evolve in the future.

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Appendix A

Table A1 Building parameters for the Standard Test Case

Parameter	Value (Units)	Parameter Correlation
m_{zone}	13561 kg	Value from SAP
m_{si}	15181 kg	Value from SAP
m_{se}	15181 kg	Value from SAP
m_{im}	13327 kg	IDEAS only, calibration parameter
$\dot{m}_{v}$	0.0377 kg/s	Value from SAP
C_{zone}	1129 J/(kg·K)	Value from SAP
C_{s}	949.5 J/(kg·K)	Value from SAP
C_{im}	1000 J/(kg·K)	IDEAS only, calibration parameter
C_{a}	1005 J/(kg·K)	Standard Value
U_{w}	1.5 W/(m^2·K)	Value from SAP
U_{f}	0.7 W/(m^2·K)	Value from SAP
U_{r}	2.3 W/(m^2·K)	Value from SAP
U_{im}	2.5 W/(m^2·K)	IDEAS only, calibration parameter
U_{d}	2.1 W/(m^2·K)	Value from SAP
U_{s}	1.05 W/(m^2·K)	Value from SAP
A_{w}	16.9 m^2	Value from SAP
A_{f}	44.4 m^2	Value from SAP
A_{r}	44.4 m^2	Value from SAP
A_{im}	133.3 m^2	IDEAS only, calibration parameter
A_{d}	3.8 m^2	Value from SAP
A_{s}	81.8 m^2	Value from SAP
h_{i}	7.69 W/(m^2·K)	Standard Value
h_{e}	25 W/(m^2·K)	Standard Value
k_{w}	0.303 W/(m·K)	Value from SAP
d_{w}	0.2375 m	Value from SAP

Appendix B

Nomenclature

m_{zone} - Mass of internal air and furniture in environmental zone
m_{si} - Mass of internal structure
m_{se} - Mass of external structure
m_{im} - Internal mass
$\dot{m}_v$ - Infiltration rate
C_{zone} - Thermal capacity of environmental zone (air & furniture)
C_s - Thermal capacity of building structure
U_w - U-value of windows
U_f - U-value of floor
U_r - U-value of roof
U_d - U-value of doors
U_s - U-value of structure
U_{im} - U-value of internal mass
A_w - Surface area of windows
A_f - Surface area of floor
A_r - Surface area of roof
A_d - Surface area of doors
A_{im} - Surface area of internal mass
A_s - Surface area of structure
h_i - Internal air heat transfer coefficient
h_e - External air heat transfer coefficient
k_w - Equivalent thermal conductivity of the structure
d_w - Thickness of the structure